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Author(s):	Milenski, Helen Marie Schmalzer, Andrew Michael Kelly, Daniel Mueller, Alexander H
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Structure Property Studies for Additively Manufactured Parts

Authors: Helen Milenksi[1], Andrew M Schmalzer[1], Daniel Kelly[1], Alexander H Mueller[1]

[1]Chemical Diagnostics and Engineering, Chemistry Division

Los Alamos National Laboratory, Los Alamos, NM 87545

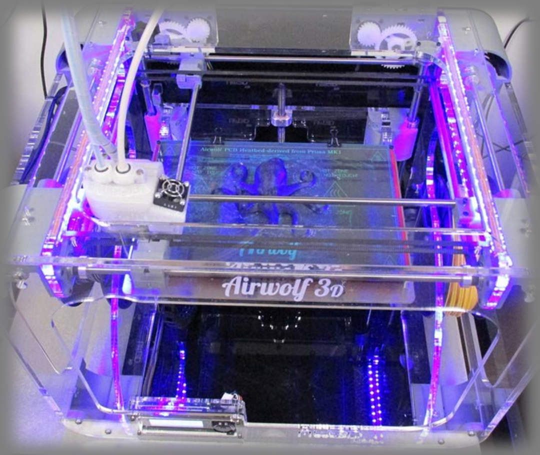
Abstract

Additive manufacturing (AM) provides the ability to create materials with tailored properties, based on fill structure and density. Likewise, AM feedstocks can be modified or synthesized to provide controlled chemical, mechanical, and transport properties. Using the Fused Deposition Modeling (FDM) process, we study the effect of infill architecture and fill density on Acrylonitrile Butadiene Styrene (ABS) parts to understand their impact on the mechanical response and overall strength of the finished parts. These architectures are built on an Airwolf HD2x with these varying infills (from the slicing program Matter Controller) to form both cylindrical and rectangular prism geometries of the same volume and cross sectional area. Once built, we load these samples in uniaxial compression test frame and compare the resulting mechanical responses.

Next, we focus on an alternative AM process known as Direct Ink Write (DIW). DIW is a more recent type of AM that enables the production of structured elastomeric materials. The feedstocks for this process are thermosetting Polydimethylsiloxane (PDMS) resins that are filled with a networking additive such as fumed silica to provide a yield stress, while still allowing the fluid to be shear-thinning. The yield stress is crucial in this feedstock to prevent the material from flowing before it is cured. These fluids are extruded using a pressure controlled Nordson Engineered Fluid Dispensing (EFD) system to lay out materials in computer controlled patterns on an Aerotech linear positioning stage. These materials are built up layer wise, and then cured at high temperature after printing to solidify the final geometry. With these materials, we study structure property relationships relating to the network density of Face Center Cubic (FCC) structures.

Instrumentation & Software

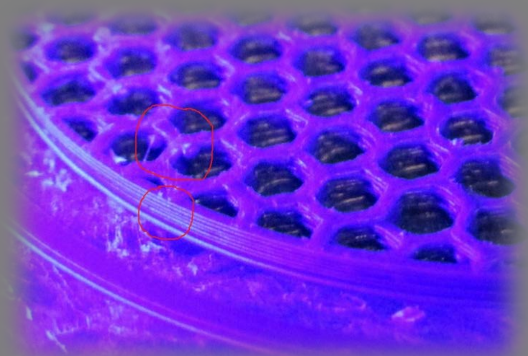
- Airwolf HD2x
  - Fused Deposition Modeling
    - ABS
    - PLA
    - Nylon
    - Etc.



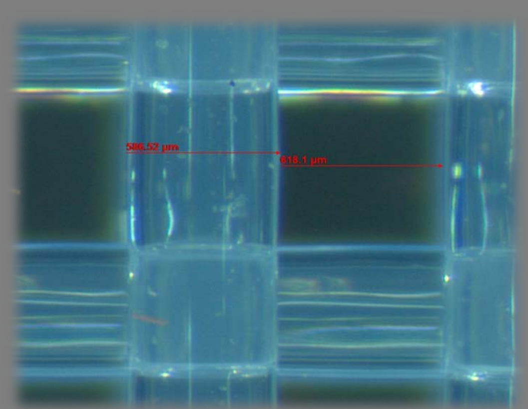
- Aerotech
  - Direct Ink
    - SE1700
    - AMS-xx
    - Liquid Feedstock

Materials of Interest

- ABS
  - Thermoplastic
  - Deposition Dependent Resolution.
  - Although prints are well defines, there is still a stochastic nature of the properties resulting from manufacturing defects

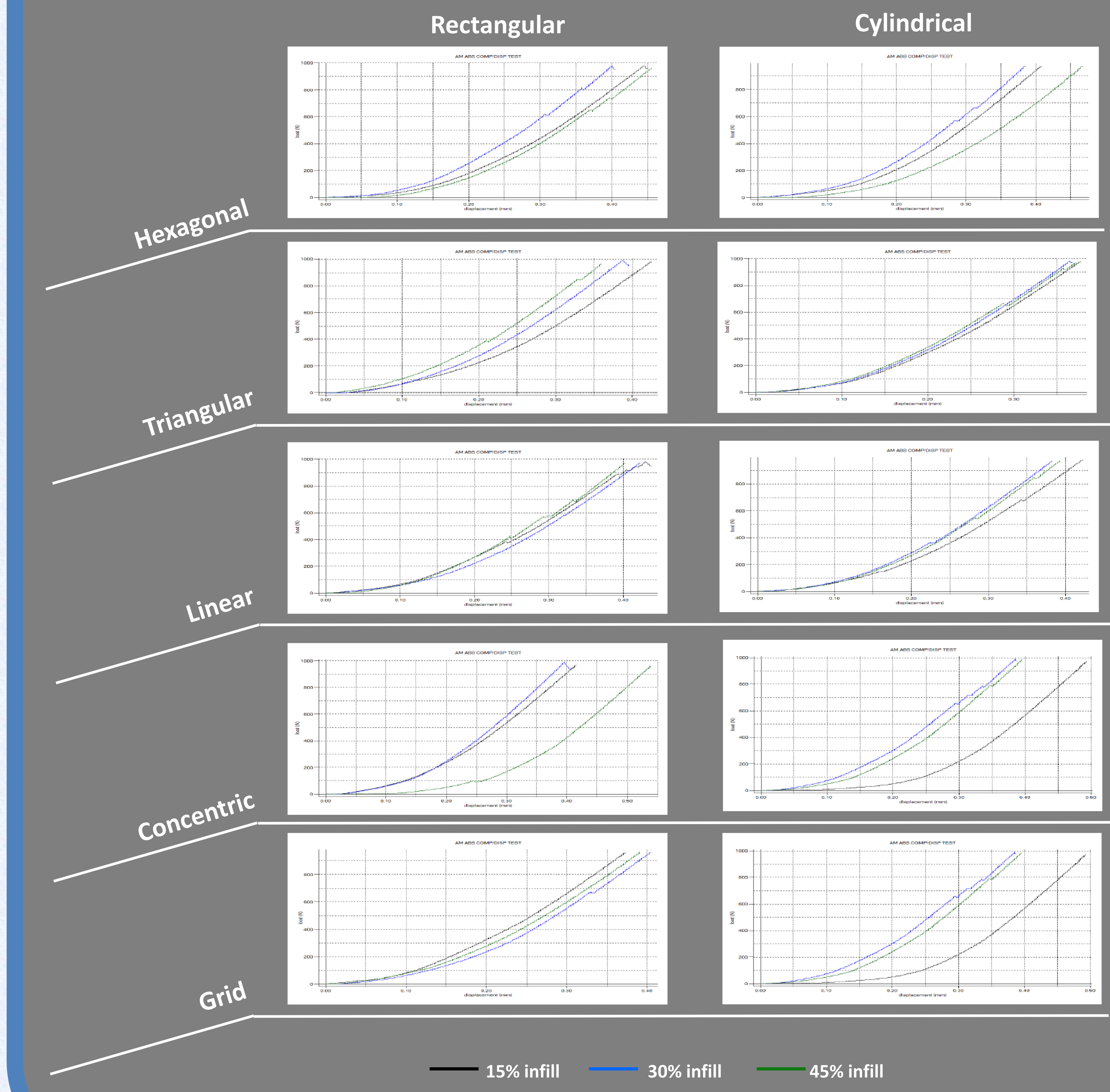


- SE 1700 Dow Corning
  - Thermosetting PDMS
  - Shear-thinning yield-stress (non-flowing under self weight) fluid
  - Heat curing process at 150°C



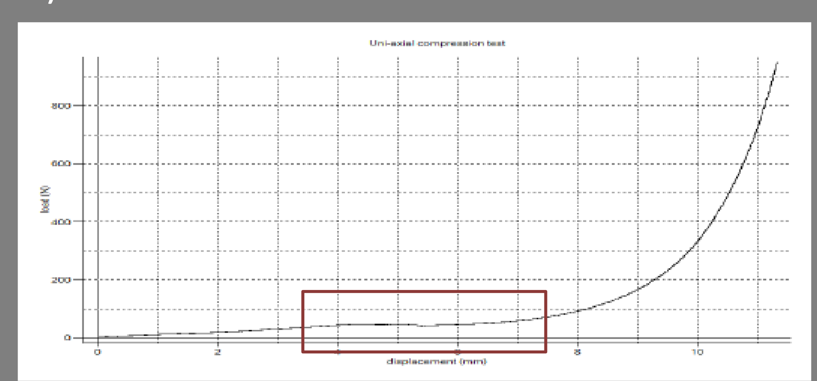
- Additive Manufacturing Silicone (AMS)
  - Thermosetting PDMS
  - Similar to SE1700, but with completely controlled chemistry.
  - Filled with surface modified silica and carbon nanofibers.

Load Deflection Results for FDM Structures



Load Deflection Results for DIW Structures

A)



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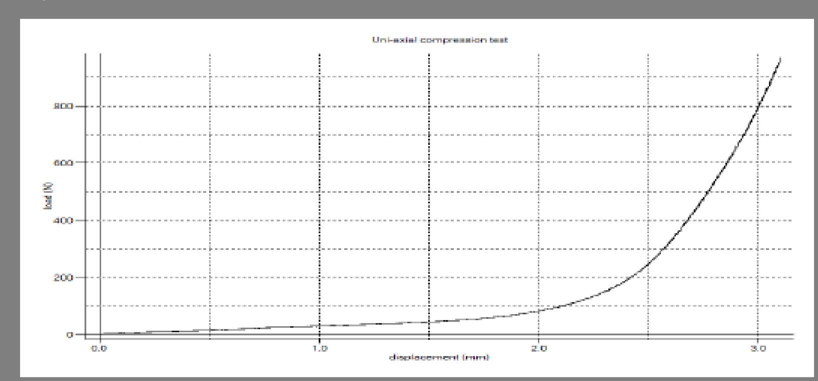
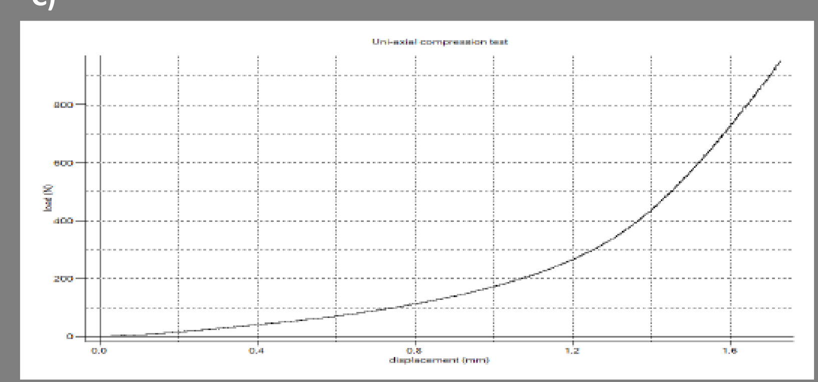


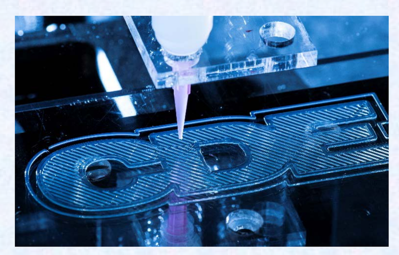
C)



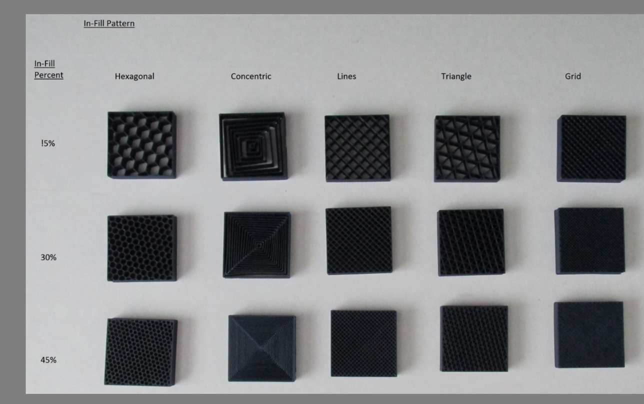
A) SE1700 FCC cube B) SE1700 FCC flat pad C) CNF filled AMS FCC flat pad.

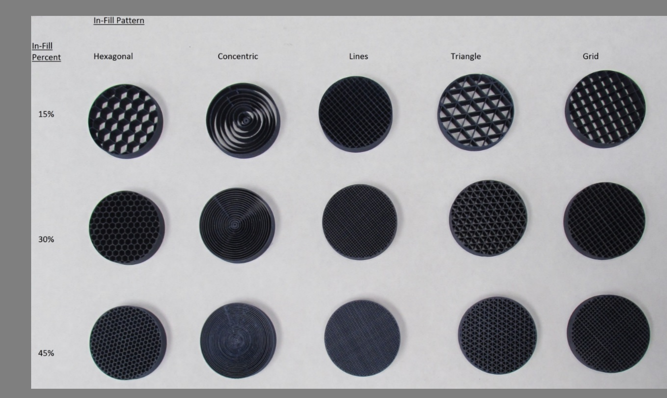
In the FCC cube, we notice that upon buckling (shown by the red box), the structure exhibits a negative elasticity. This interesting result, will be a starting point for future work, where we try to identify the various parameters a structure can exhibit before this phenomena occurs.

We notice markedly different responses for the unfilled versus CNF filled Silicone resins. We hope to understand in the future how the architecture might play a role in this response.



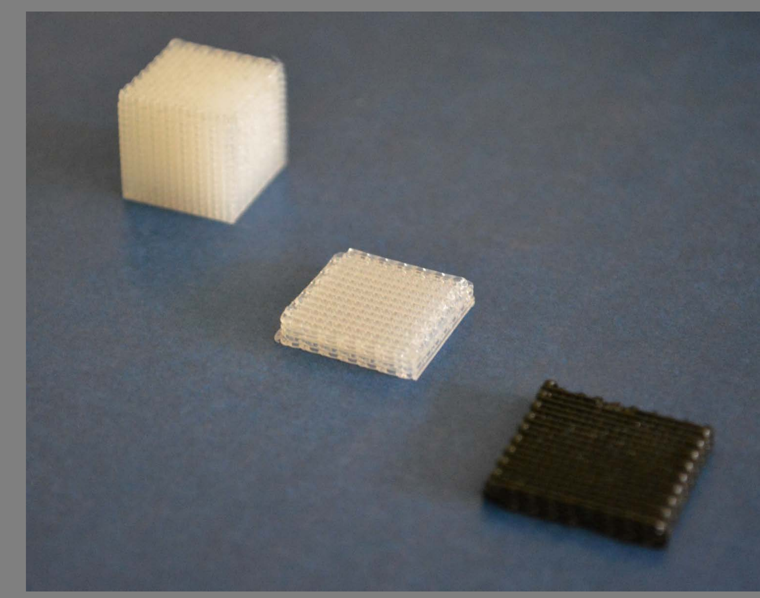
ABS Architectures





We print several different architectures using the FDM process. We print these parts out of Acrylonitrile butadiene styrene (ABS), which is a common FDM feedstock. We print these architectures without top or bottom solid faces to limit the impact of edge effects on the final part. The part architectures are limited to the fill structures available in the slicing program. These patterns are printed in both circular and rectangular cross sections, to see if axis symmetry makes a difference, the dimensions of the circular cross section parts are chosen to match the area of the rectangular cross sectional area.

DIW Architectures



From top left to bottom right: SE1700 FCC cube, SE1700 FCC flat pad, CNF filled AMS FCC flat pad.

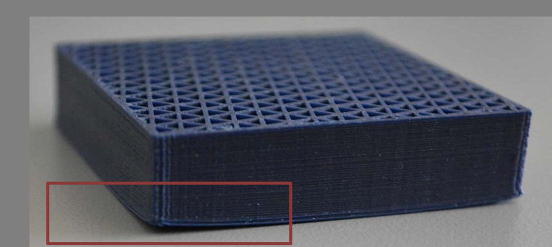
For the DIW parts, we built structures from several different silicone feed stocks, and into different size shapes. These materials are printed in an FCC structure, because of the simple nature of the structure. We post preliminary results relating to the load/deflection properties of these materials, and point out some interesting findings.

These materials are filled with silica, which creates a network in the fluid such that materials resist flow prior to curing. The addition of 0.5 wt. % carbon nanofibers is to identify how these materials will benefit structurally.

There is some difficulty in producing a CNF filled resin that does not jam the nozzle tips. Our work has produced a method for reliably printing CNF filled elastomeric materials, that can be further studied.

Peel up

In general, we notice a distinct increase in "peel up" in the ABS parts printed in the rectangular prism geometry. We believe this to be a result of a combination of the corner to corner distance in the square parts, and the stress concentrations that occur at the 90° corner. We find the triangular infill to demonstrate this problem the most.



Conclusions/Future work

We have demonstrated that the load deflection response for these materials vary based on their internal structure, likewise, their shape governs how much residual stresses can effect the *peel up* of these parts. In the future we hope to:

- Identify the stress/strain relationship resulting from internal structure
- Identify network density and it's effect on the mechanical response
- Identify how the loading of CNF effects the mechanical response with respect to wt. %
- Identify how the network density and volume effect the structure, such that negative stiffness can be avoided.

Acknowledgements

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